Jet Propulsion Laboratory
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GRACE Follow-On International Challenges

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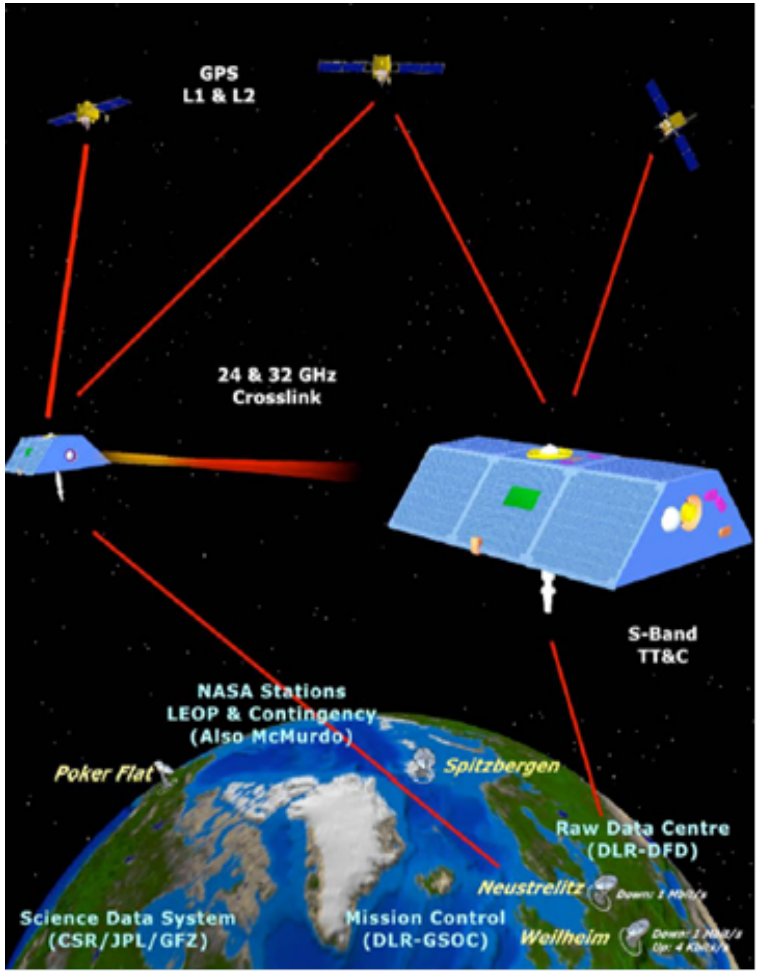
Introduction

- The Gravity Recovery And Climate Experiment (GRACE) Mission, a collaboration between NASA, DLR, and German Research Centre for Geosciences, was launched March 17, 2002 from Plesetsk, Russia.
- The GRACE Mission is the only NASA mission capable of monitoring mass variations in the Earth system.
- Mission lifetime was 5 years, but has continued to operate for 15 years
- End of mission is dependent on solar activity, fuel, instrument and - most likely - battery status.

- NASA and GFZ responded to a science community call for a continuation mission - GRACE Follow-On - which was authorized for development January 12, 2012.

- This talk will focus on many of the international challenges encountered during the on-going development of GRACE Follow-On.

Project Overview



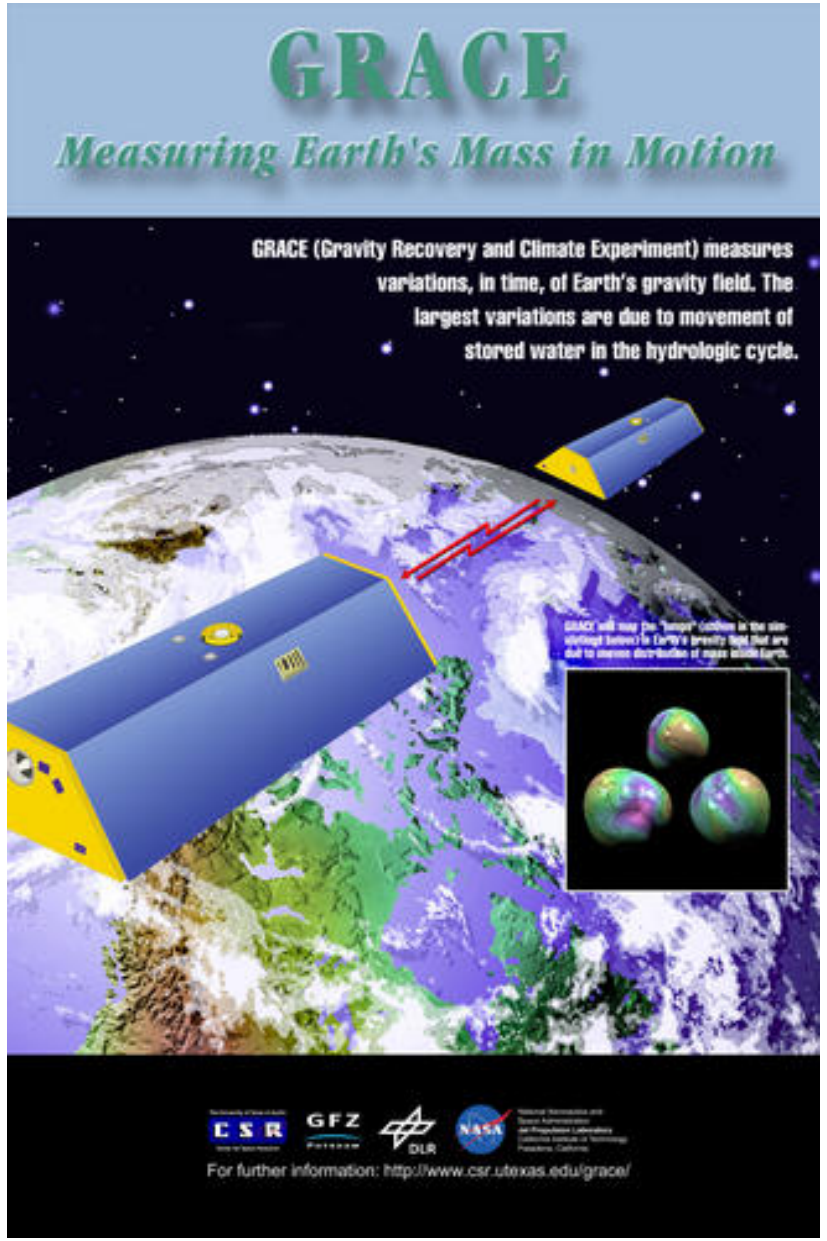
NASA – Mission Lead	**JPL** Project management, Science & Science processing, Mission Assurance, Spacecraft, Accelerometer, Microwave and Laser Ranging Instruments, Mission management
Partners	**GFZ - German Research Centre for Geosciences (GeoForschungsZentrum)** Science & science processing, Mission operations, Optical components of Laser Ranging Interferometer, Launch Services, with support from STI, AEI, DLR
Launch	December 2017 on GFZ contributed SpaceX Falcon-9 launch vehicle from Vandenberg, California
Orbit	Near-circular Polar Orbit, 500 km altitude, 89º inclination
Lifetime	5 years baseline
Spacecraft	JPL Subcontract to Airbus DS, Friedrichshafen, Germany
Instruments	Accelerometer (ACC) – JPL Subcontract to ONERA, France Microwave Instrument (MWI) – JPL in-house build Laser Ranging Interferometer (LRI) – JPL and GFZ collaboration Laser Retroreflector (LRR) – GFZ
Mission Ops	Mission Operations contributed by GFZ via German Space Operations Center (GSOC), Oberpfaffenhofen, Germany
Science Data	Science Data System (SDS) managed by JPL with centers at JPL, UT-CSR, GFZ.

Mission Objective and Approach

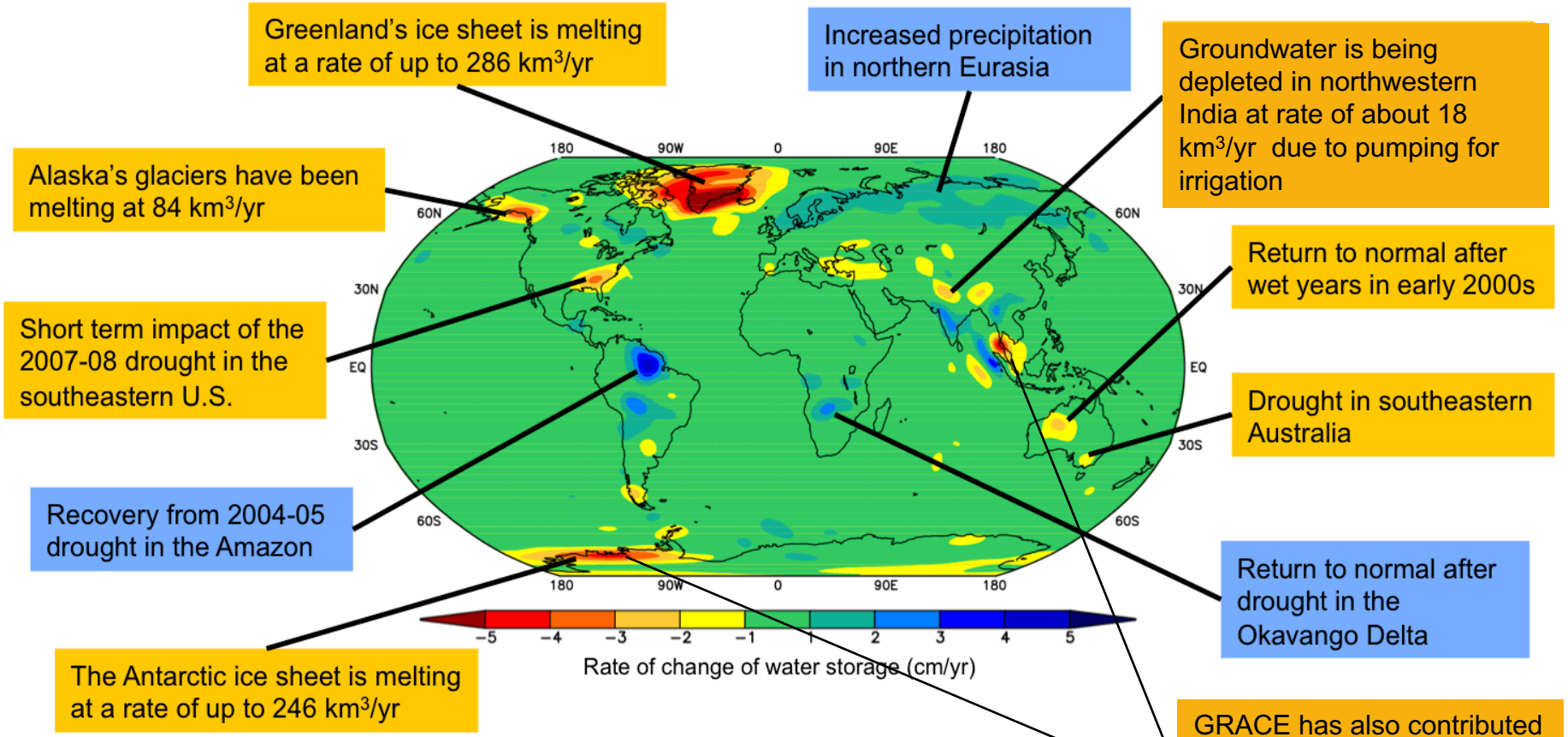
- The Primary Objective of the Follow-On Mission is to continue the GRACE Mission's 15-year record of key climate change observations based on high-resolution global models of Earth's gravity field and its variation over time.

- A Secondary Objective is to demonstrate inter-satellite laser ranging technology in support of future GRACE-like and other Agency missions.

- Mission Approach
  - Minimize risk and maximize use of heritage systems and partnerships from GRACE, including international partnership with Germany in science, ground systems, operations, and launch services.
  - Deliver products to the science community through the existing channels developed and used for GRACE.



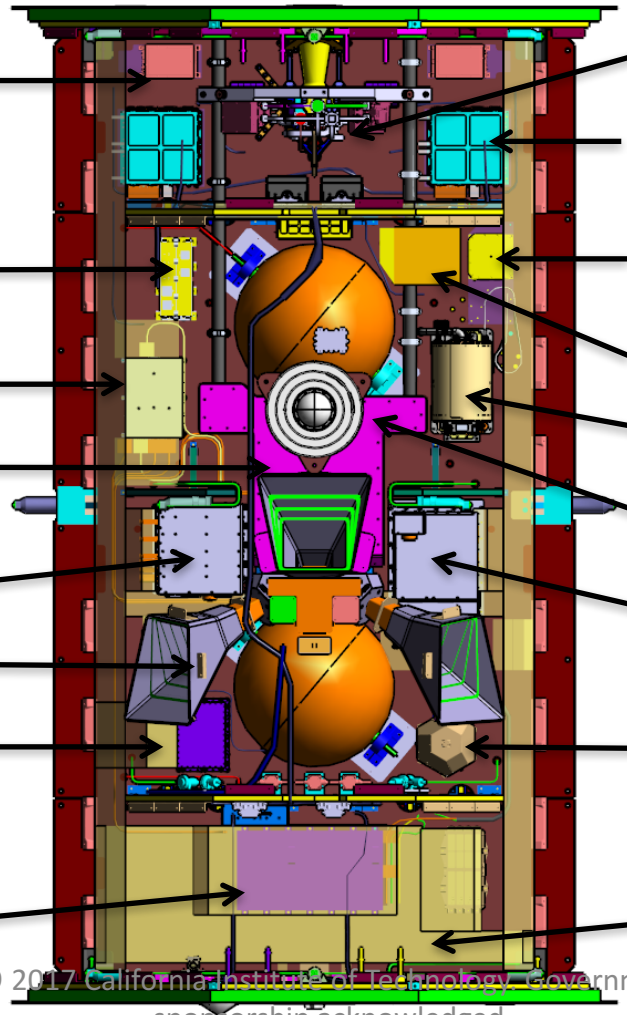
Mission Science - Major Observed Mass Trends



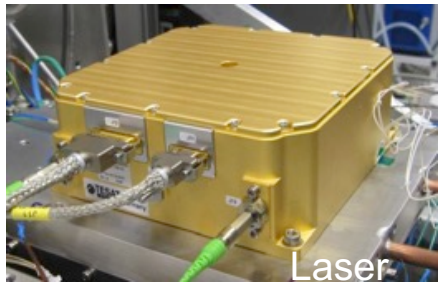
GRACE recorded gravity with sufficient accuracy to measure monthly variations in the global gravity field related to mass transport. Prior to GRACE, much of this information was unavailable (e.g., the accumulated water and ice mass variability).

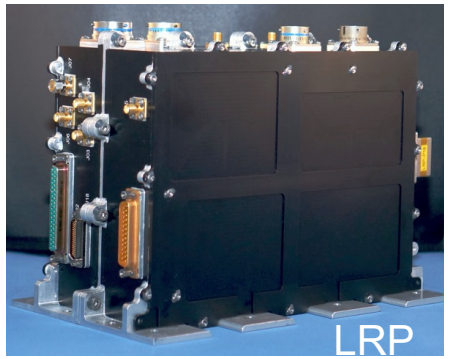
International Participation Examples

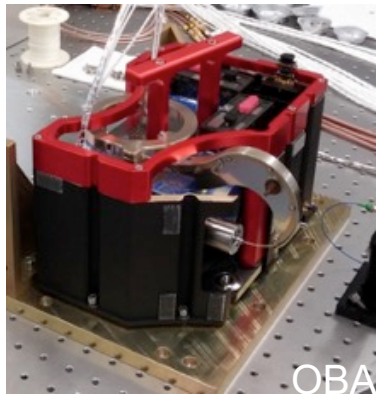
GRACE-FO Spacecraft Components and Countries

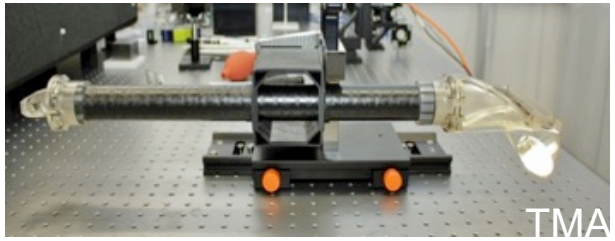


Working Partnerships









Laser Ranging Interferometer Components

- Challenge: Building open and trusting relationships
- GRACE-FO relationships developed over many years based on GRACE and LISA heritage
  - NASA – GFZ roles and responsibilities are codified in a Memo of Understanding (MOU).
  - JPL – GFZ working relationship defined by a Co-operative Project Plan (CPP).
  - Spacecraft, Accelerometer, and Microwave Instrument Contract relationships derived from GRACE heritage with updated technology from SWARM.
  - Laser Ranging Interferometer partnerships derived from LISA Pathfinder.

Establishing open and trusting relationships among partners is crucial for success in an international mission.

Communication and Reporting

- Challenge: Understanding problems and issues in a timely manner.
  - ITAR constraints required significant effort to insure appropriate technical communication and coordination between EEE parts suppliers and European developers.
    - GRACE-FO switched from ITAR to EAR in 2015.
  - English language used primarily for technical discussions, reporting, and review. Extra diligence was required to insure that common understanding was achieved.
  - Differences in ”standard” practices often resulted in wrong base assumptions.
  - An architecture for regular reporting at all levels of the project was established early.
    - Communication occurred at weekly, monthly, and quarterly intervals across all levels of the project.
    - Significant effort invested in holding face-to-face Technical Interchange Meetings and Project Reviews with all suppliers.

Managing cost, schedule, and making good risk decisions cannot be done without accurate and timely information.

Standards and Practices

- Challenge: Identification of applicable standards and practices.

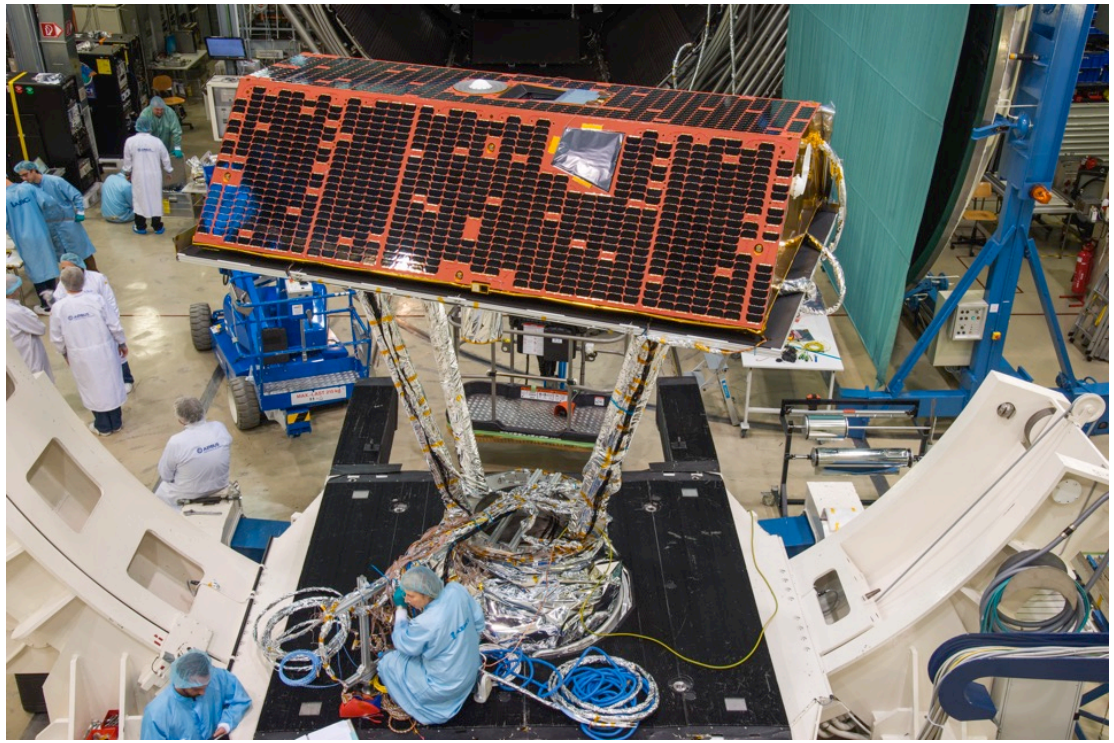
- NASA vs ESA Product Development Requirements
  - A Project Policy was established early to minimize changes to supplier standard practices.
  - A “Gap Analysis” was performed to understand clearly the differences in production requirements, tools, and processes across all suppliers.
  - Standard tools and monitoring were established early to track and resolve non-conformances at defined levels.

GRACE-FO Spacecraft at Airbus

Understanding partner practices, and limiting changes to those practices, is a key factor in minimizing cost and schedule risk.

Cultural Considerations

- Challenge: Understand cultural considerations, their benefits, and their impacts to the project.



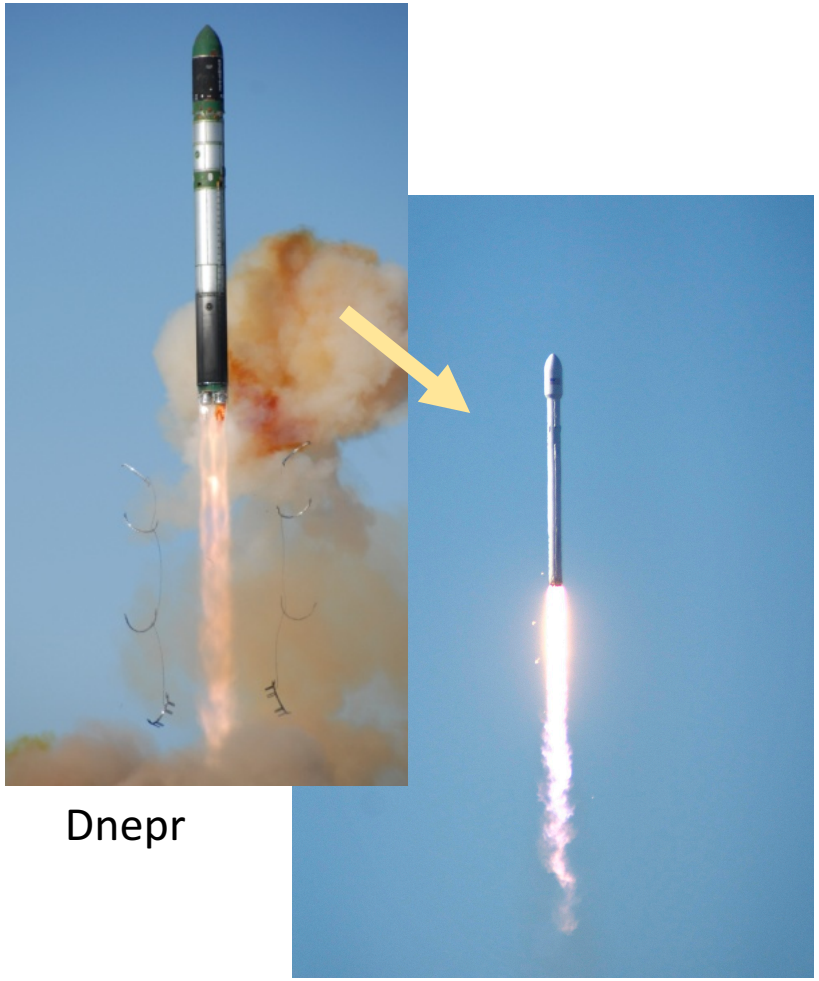
GRACE-FO Spacecraft Test at IABG

- Government labor laws and restrictions
- Work vs Family expectations and limitations
- Holidays and vacation planning
- Variations in standard work practices
- Management / Employee relationships
- Educational requirements
- Language issues
- Culturally induced assumptions

Cultural considerations play a key role in developing realistic expectations for project planning, communication, and workflow management.

Launch Service

- Challenge: Significant changes occurred in launch vehicle planning.
  - Original launch planning for GRACE-FO included a Kosmotras provided Dnepr launch from Baikonur, Kazakhstan.
    - Language and document translation difficult and time consuming.
  - Launch site moved to Yasny, Russia.
    - Problematic given nearby location of open-air asbestos mining. Launch site visit never approved by Russian military.
  - Dnepr launch service stopped by Russia and GFZ forced to seek an alternate plan for launch service contribution.
  - Agreement reached to share ride with Iridium on SpaceX Falcon-9 from Vandenberg AFB by early 2018.



Dnepr

SpaceX Falcon-9

Summary

- Addressing the organizational challenges of an international collaborative space mission has been crucial to assuring the success of the development and implementation of the GRACE Follow-On Mission.
- In addition to planning the twin spacecraft with robust technical designs, the mission was also planned with a robust implementation and test schedule and with consideration for the cultural and organizational differences.
- Significant impacts in launch service planning have been addressed using an international and cost-effective collaboration with Iridium and SpaceX
- GRACE Follow-On is continuing NASA's successful international collaborations in space science and is on track for a launch in early 2018.